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Earth rheology in Iceland: new constraints from InSAR observations and models of crustal deformation induced by glacial surge and GIA

Amandine Auriac (1), Freysteinn Sigmundsson (2), Andy Hooper (3), Karsten Spaans (3), Helgi Björnsson (2), Finnur Pálsson (2), Virginie Pinel (4), and Kurt L. Feigl (5)

(1) Department of Geography, Durham University, Durham, UK (ama3@hi.is), (2) University of Iceland, Institute of Earth Sciences, Reykjavík, Iceland, (3) School of Earth and Environment, University of Leeds, Leeds, UK, (4) Université de Savoie, IRD, Le Bourget du lac, France, (5) Department of Geosciences, University of Wisconsin-Madison, Madison, USA

About 11% of Iceland is covered by glaciers. The largest ice cap, Vatnajökull, has an area of ∼8100 km^2 with an average ice thickness of ∼380 m. Climate changes since the late 19th century has induced significant ice loss at Icelandic glaciers, resulting in a broad Glacial Isostatic Adjustment (GIA) uplift signal in the country. Furthermore, many of the major outlets from Icelandic ice caps are known to surge with a quiescent period of a few to up to ∼10 decades. During a surge (lasting only a few months) large quantities of ice are transported to the glacier and terminal region from the interior zone of the ice caps. Due to this large scale mass transport, a surge implies a local crustal subsidence. In 1993 to 1995, the major outlets from SW-Vatnajökull surged. Deformation due both to GIA and the surges was observed and used to infer the properties of the crust and mantle beneath Iceland through modelling.

Interferometric Synthetic Aperture Radar (InSAR) data from 1992-2002, providing high resolution ground observations, were used to measure the GIA uplift and surge-induced subsidence with mm to cm accuracy. InSAR time series and velocity estimates reveal a GIA signal of up to 25-28 mm/yr close to the ice cap. We disentangled the near instantaneous surge-induced crustal signal from the long-term GIA by inverting for a step function at the time of the surge, superimposed on the assumed linear GIA deformation rate. This yielded a surge-induced deformation signal reaching up to 75 mm at the ice edge.

Finite element modelling is performed to reproduce each signal and infer some of the Earth properties. Each model is compared to the observations and a probability distribution of our free parameters is obtained using a Bayesian approach. For the surge-induced deformation, we use elastic modelling with one or two elastic layers and a digital map of the ice mass distribution after the surge, created from surface elevation measurements and glacier surface DEMs prior to and after the surge. We solve for the value of the Young's moduli (E) and Poisson's ratios (v) and find that the best-fitting models are those using a one-kilometer thick top layer with a v=0.17 and E between 12.9-15.3 GPa, underlain by a layer with v=0.25 and E from 67.3 to 81.9 GPa. For the GIA, we use visco-elastic modelling, running from 1890-2010, and using three layers (two elastic layers as defined above on top of a visco-elastic layer). We then solve for the total elastic thickness and the viscosity of the third layer. These models provide a complete Earth model for the crust and mantle beneath Iceland. Results demonstrate that InSAR data and finite element models can be used successfully to reproduce crustal deformation induced by ice mass variations at Icelandic ice caps.